

A Long View of GNSS Evolution

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My Perspective and a Disclaimer

- ◆ Nearly 40 years leading the development mostly of commercial Satellite Navigation products
- ◆ Member of the WAAS Independent Review Board
- ◆ Significant contributions to modernization of civil and military GPS signals (L5, L2C, M Code, L1C)
- ◆ Participant in International Working Groups on GPS, Galileo, QZSS, and GLONASS

The following are personal observations and do not necessarily represent the views of others

27 Years with 3 GPS Signals

Signal/SV	IIR			
L1 C/A	✓			
L1 P(Y)	✓			
L1 M				
L1C				
L2 P(Y)	✓			
L2C				
L2 M				
L5				

**1978 to
2005**

IIR-M Satellites Add Three More

Signal/SV	IIR	IIR-M		
L1 C/A	✓	✓		
L1 P(Y)	✓	✓		
L1 M		✓		
L1C				
L2 P(Y)	✓	✓		
L2C		✓		
L2 M		✓		
L5				

**1978 to
2005**

2005

IIF Satellites Add L5

Signal/SV	IIR	IIR-M	IIF
L1 C/A	✓	✓	✓
L1 P(Y)	✓	✓	✓
L1 M		✓	✓
L1C			
L2 P(Y)	✓	✓	✓
L2C		✓	✓
L2 M		✓	✓
L5			✓

**1978 to
2005**

2005

200?

GPS III Adds L1C

Signal/SV	IIR	IIR-M	IIF	III
L1 C/A	✓	✓	✓	✓
L1 P(Y)	✓	✓	✓	✓
L1 M		✓	✓	✓
L1C				✓
L2 P(Y)	✓	✓	✓	✓
L2C		✓	✓	✓
L2 M		✓	✓	✓
L5			✓	✓

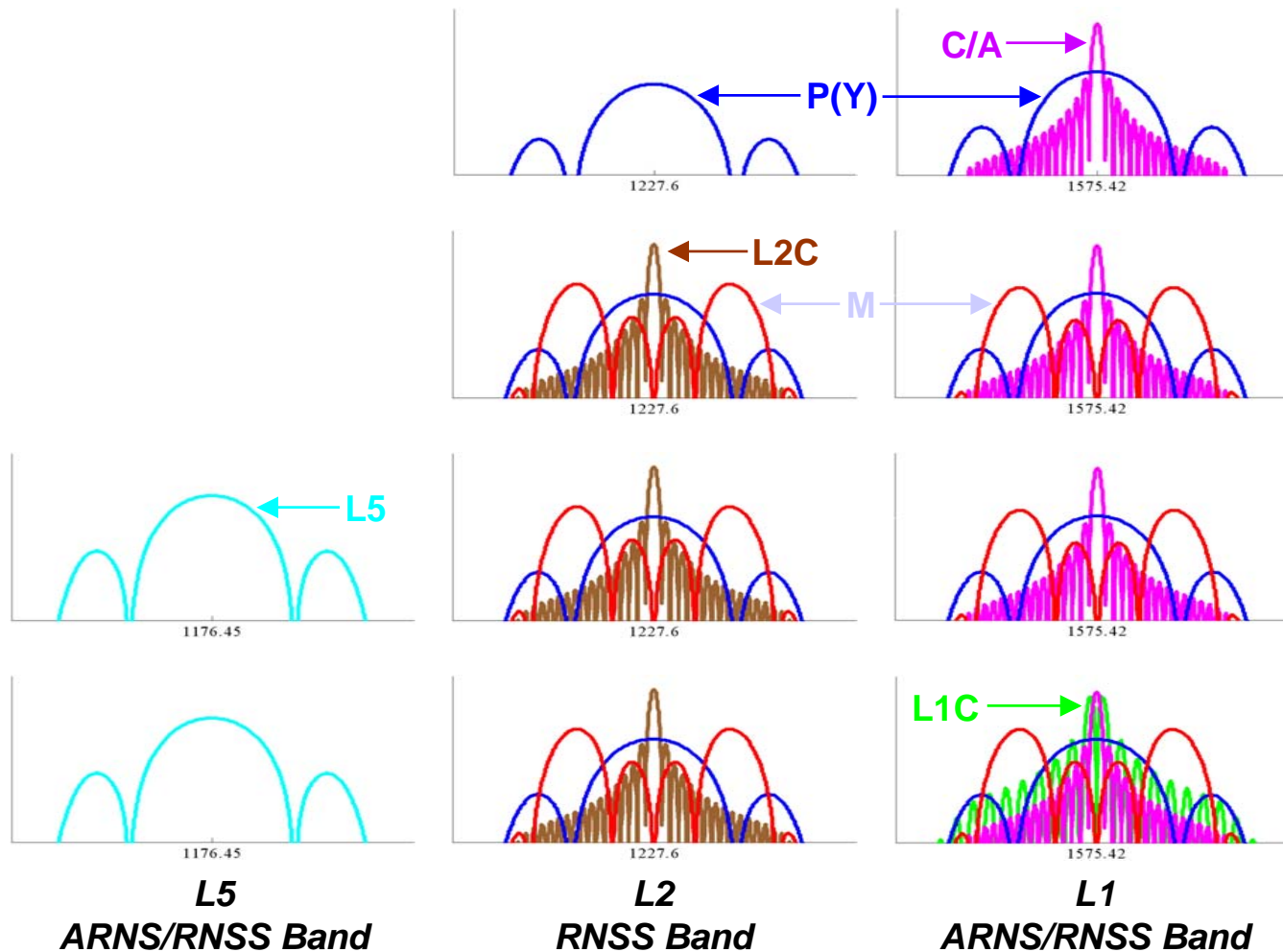
**1978 to
2005**

2005

200?

201?

Modernized GPS Signal Spectra



Current GPS
Dual Frequency w/
Semi-codeless P(Y)

Block IIR-M
Launch 2005
Dual Frequency
L1 C/A & L2C

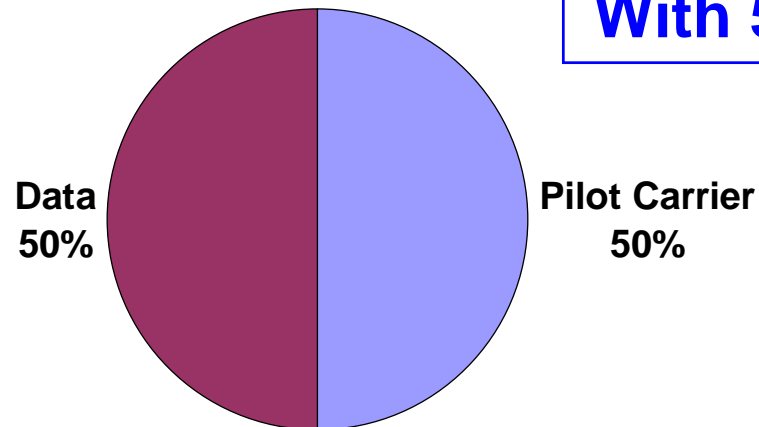
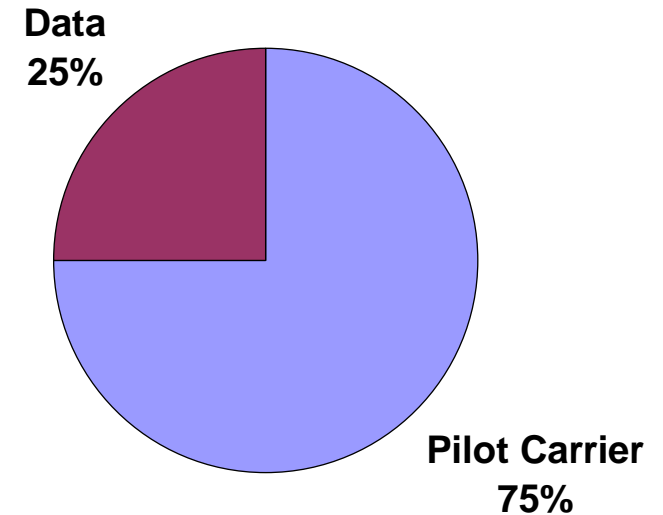
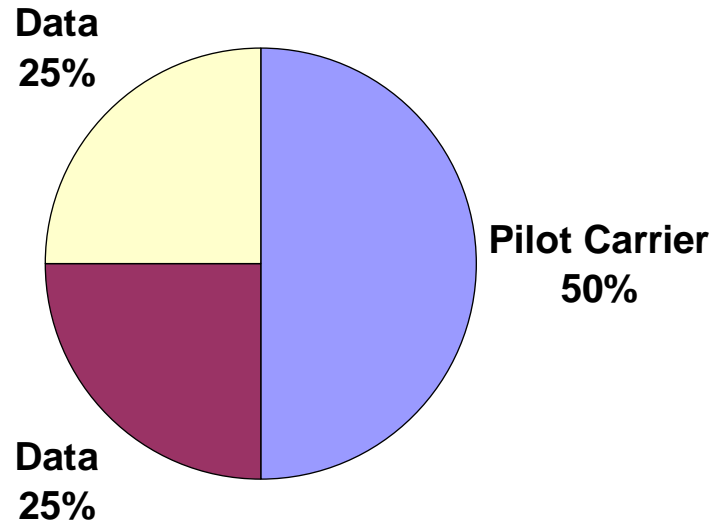
Block IIF
Launch 2007
Three Frequency
L1 C/A, L2C, & L5

Block III
Launch 2013
L1C, L2C, L5,
& L1 C/A Code

Asking The Experts About L1C

- ◆ The U.S. did a remarkable thing in designing L1C
- ◆ We asked GPS experts what signal characteristics they preferred

Five Signal Options Were Offered



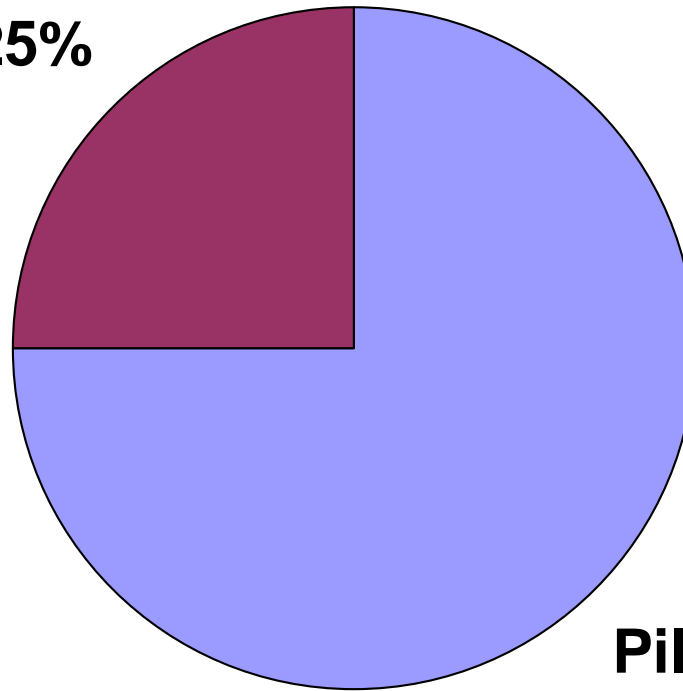
With 50 or 75 bps?

S50/25% Option Selected

Data at 50 bps

Signal Power Split

**Data
25%**



**Pilot Carrier
75%**

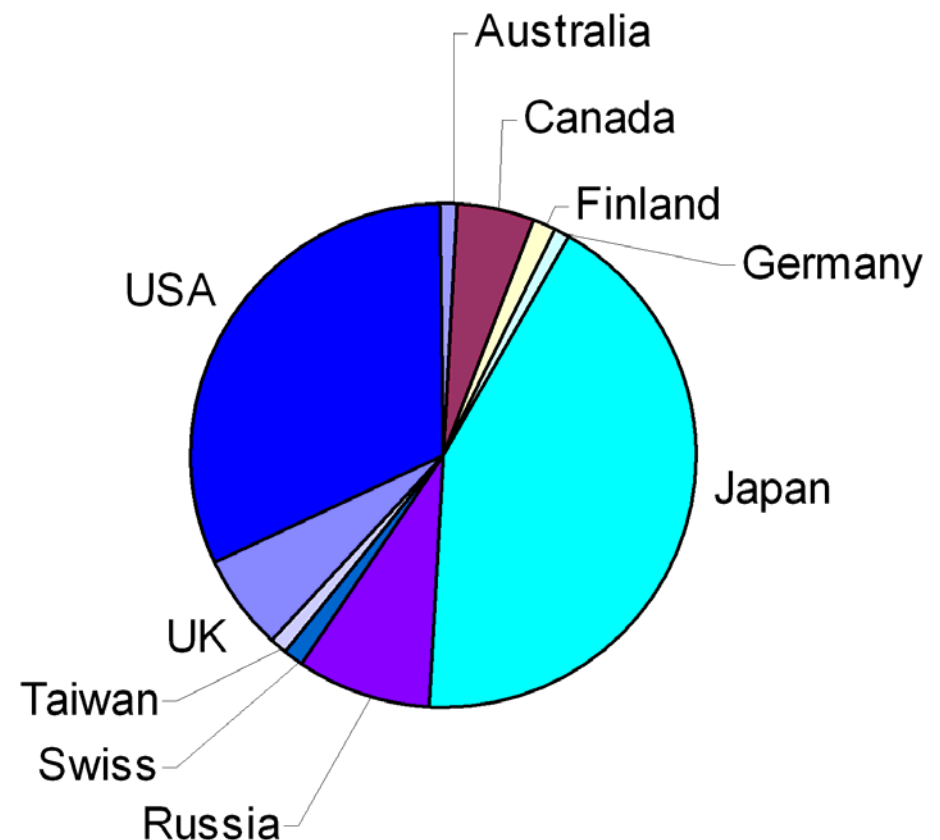
**Best Code
& Carrier
Track
Threshold**

L1C Presentations and Responses

33 L1C Presentations (Sequence By Country)

1. Japan
2. Russia
3. Germany
4. United Kingdom
5. United States
6. Canada
7. Switzerland
8. Australia
9. Taiwan

81 Responses by Country



Responses by Organization (1 of 3)

- | | |
|--------------------|-----------------------|
| 1. AIST | 15. U.S. FRA |
| 2. AIST | 16. Freq_Electronics |
| 3. AJ_Systems | 17. Furuno |
| 4. ASBC | 18. Garmin |
| 5. Asia_Air | 19. Global Locate |
| 6. Calgary | 20. GNSS_Technologies |
| 7. Ceva | 21. GSI |
| 8. CMC Electronics | 22. HCX |
| 9. Colorado | 23. Hitachi |
| 10. COMPAS | 24. Hitachi |
| 11. COMPAS | 25. Imperial_College |
| 12. ENRI | 26. Japan_Coast_Guard |
| 13. ENRI | 27. Japan_Defense |
| 14. Forest_Service | 28. Japan_Surveyor |

Responses by Organization (2 of 3)

- | | |
|-----------------------|-----------------------|
| 29. JAXA | 44. NavWard |
| 30. JAXA | 45. NEC_Toshiba_Space |
| 31. JAXA | 46. NGS |
| 32. JAXA | 47. Nikon_Trimble |
| 33. JAXA | 48. Nippon_GPS |
| 34. JAXA | 49. Nokia |
| 35. JAXA | 50. Novariant |
| 36. JNS | 51. NovAtel |
| 37. JRC | 52. NTT |
| 38. Leica Geosystems | 53. Ohio_State |
| 39. Matsushita | 54. Ohio_University |
| 40. Mitsubishi | 55. Ohio_University |
| 41. NASA | 56. Pioneer |
| 42. NavCom Technology | |
| 43. Navitime | |

Responses by Organization (3 of 3)

- | | |
|----------------------|------------------------|
| 57. Qualcomm | 70. Stanford |
| 58. Rockwell_Collins | 71. Stanford |
| 59. Rockwell_Collins | 72. Surrey |
| 60. Roke | 73. Topcon |
| 61. Russian_Academy | 74. Topcon |
| 62. Seiko_Epson | 75. Trimble |
| 63. SiRF | 76. Trimble |
| 64. SkyTraq | 77. U. College London |
| 65. Sokkia | 78. U. FAF Munich |
| 66. Sony | 79. U. New Brunswick |
| 67. Space_Device_Eng | 80. U. New South Wales |
| 68. Stanford | 81. U.S. Coast Guard |
| 69. Stanford | |

By Country

34 Japan

26 U.S.

7 Russia

5 U.K.

4 Canada

1 Australia

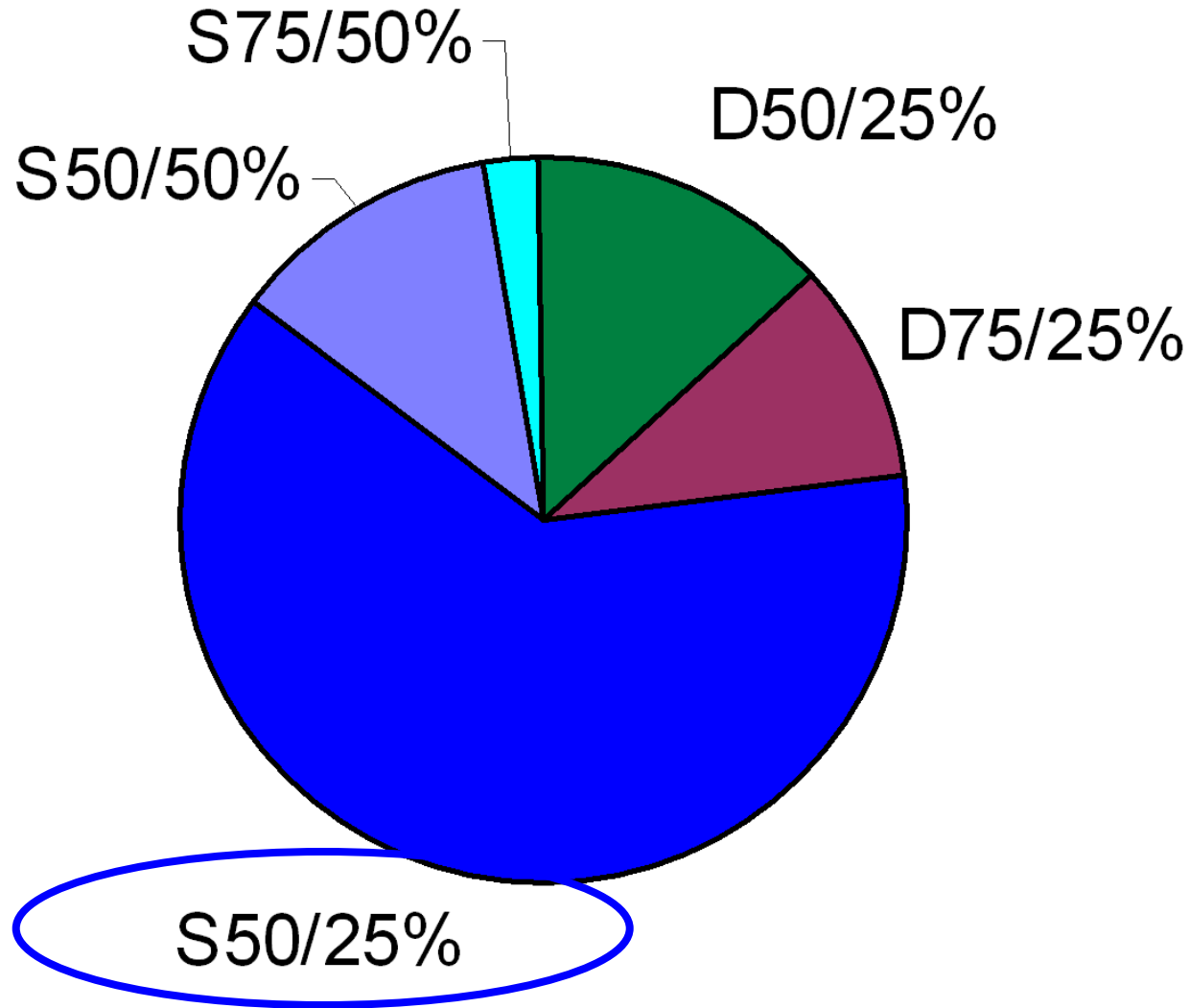
1 Finland

1 Germany

1 Switzerland

1 Taiwan

A Clear International Signal Choice



L1C Signal Philosophy

- ◆ Provide benefit to all users & applications
- ◆ Main attribute: Robustness
 - Signal acquisition and tracking
 - Code and carrier measurements
 - Spreading code correlation performance
 - Data demodulation, both speed and threshold
- ◆ GNSS measurements: the most vital service
 - Auxiliary services better provided by other means
 - Long lasting orbit and clock parameters
 - Differential corrections
 - Integrity messages

**-157 dBW =
0.87 microwatt
at 1 km distance**

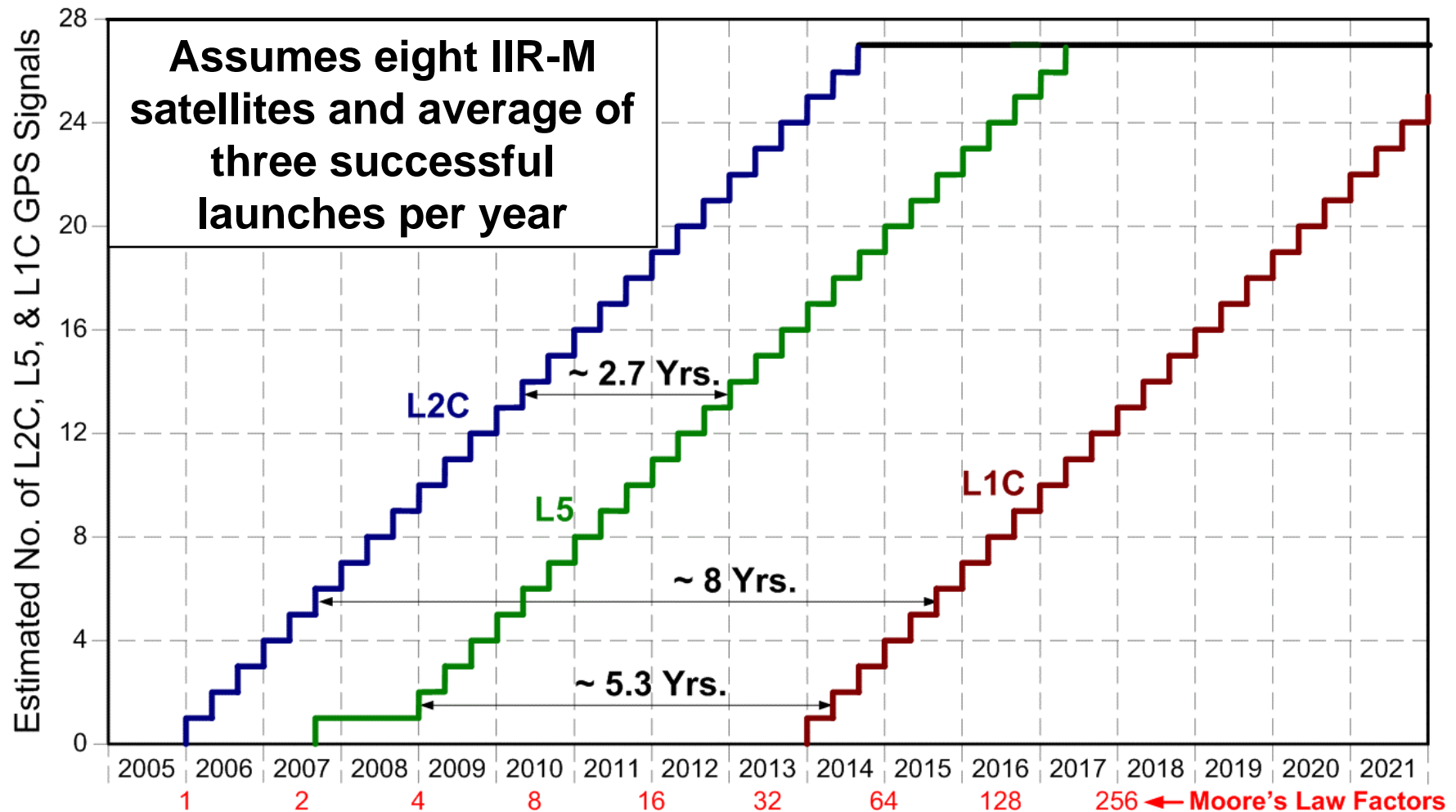
New GPS and Galileo L1 Signals

- ◆ L1 is the most important GNSS frequency
 - Required for all multi-frequency applications
 - Lowest ionospheric error for single frequency users
 - Narrow bandwidth better for low cost consumer products
- ◆ Key GPS L1C and Galileo L1 OS differences
 - GPS L1C pilot is 1.8 dB stronger than Galileo pilot
 - Galileo transmits Galileo-only integrity messages
 - Requires 125 bps data rate (4 dB less energy/bit than 50 bps)
 - GPS transmits 3 dB less message power than Galileo
 - GPS uses 2.2 dB better forward error correction (LDPC)
 - Net is a 3.2 dB GPS message robustness advantage
 - Galileo provides Galileo-only integrity messages
 - Which is better - - - or is different better?

Dispelling a Myth

- ◆ Some people continue to talk about GPS or Galileo
 - As if customers will choose between GPS and Galileo
- ◆ This is a myth
- ◆ Most future receivers will be GNSS receivers
- ◆ Users will not know or care about the signal source
- ◆ Users simply will benefit from the improved accuracy, integrity, and availability performance of a combined GNSS satellite constellation

Estimated Signal Availability (Not Official)

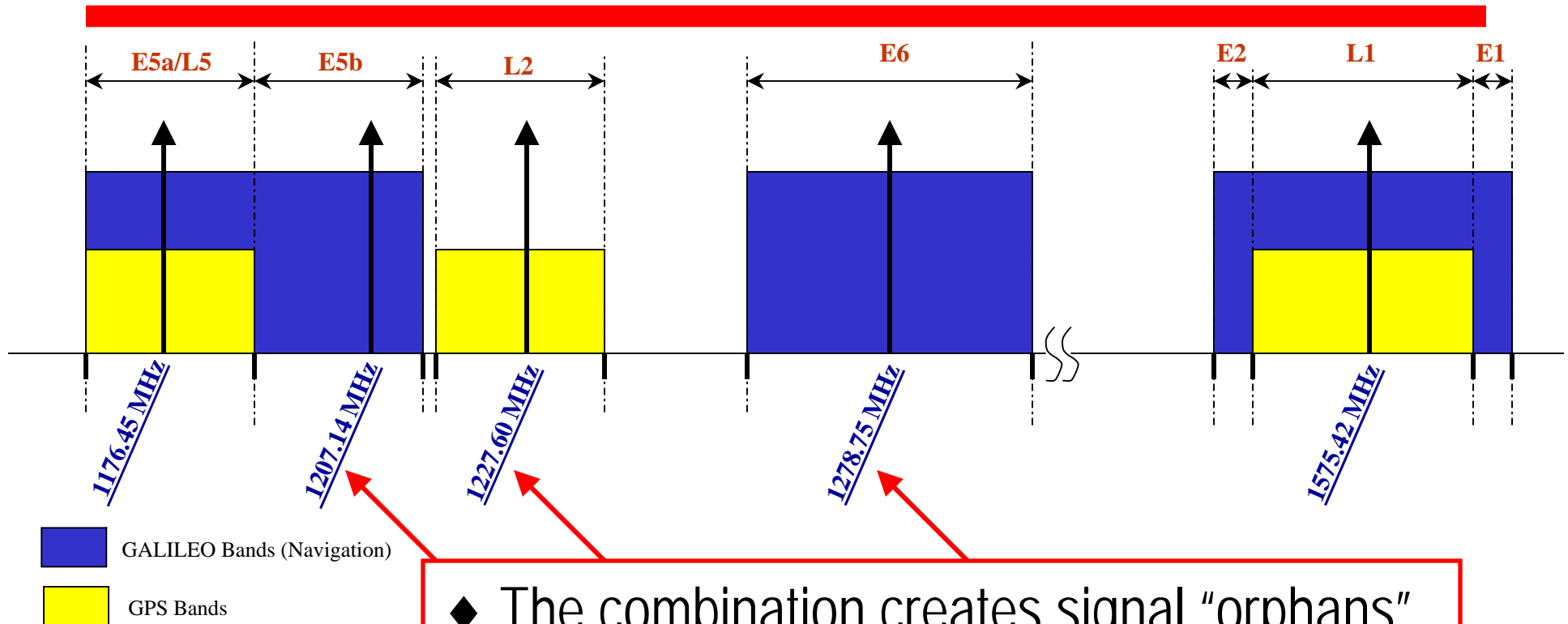


When Will Galileo Be Fully Operational?

Slow or Frantic Pace ?

- ◆ Users and receiver manufacturers see the pace of new GNSS signal deployment as extremely slow and often delayed
- ◆ Those providing the signals often think the pace is frantic to resolve the performance, cost, contractual, and schedule issues
 - An example is the GPS III procurement
 - People are working hard to resolve the issues
 - But schedule predictions have not been fulfilled
- ◆ However, change is coming, and we must prepare

Galileo and GPS Frequencies



- ◆ The combination creates signal “orphans” where GPS and Galileo do not overlap
- ◆ Why build receivers for only half the signal sources?

Transition Issues (1 of 2)

- ◆ The greatest contribution of Galileo or GLONASS to the current GPS service is more satellites, i.e., better geometry
 - Improves integrity, accuracy, and availability
 - The increased number of operational satellites is now causing more interest in GLONASS

Transition Issues (2 of 2)

- ◆ All things being equal, common GNSS frequencies will be the most widely used (give the best value)
 - Why build receivers for 1/2 or 1/3 of the satellites in view
 - Each new frequency adds cost for more complex antenna, RF filters, frequency plan, spurious interference, extra shielding, signal isolation, and calibration of differential delays
 - Galileo has only two frequencies common with GPS
 - GLONASS provides no common frequencies
 - A successful Galileo means less interest in GLONASS
 - After ~40 satellites, diminishing value for each additional one
 - Common frequency signals would make GLONASS equally as useful as GPS or Galileo
 - The marketplace makes these decisions

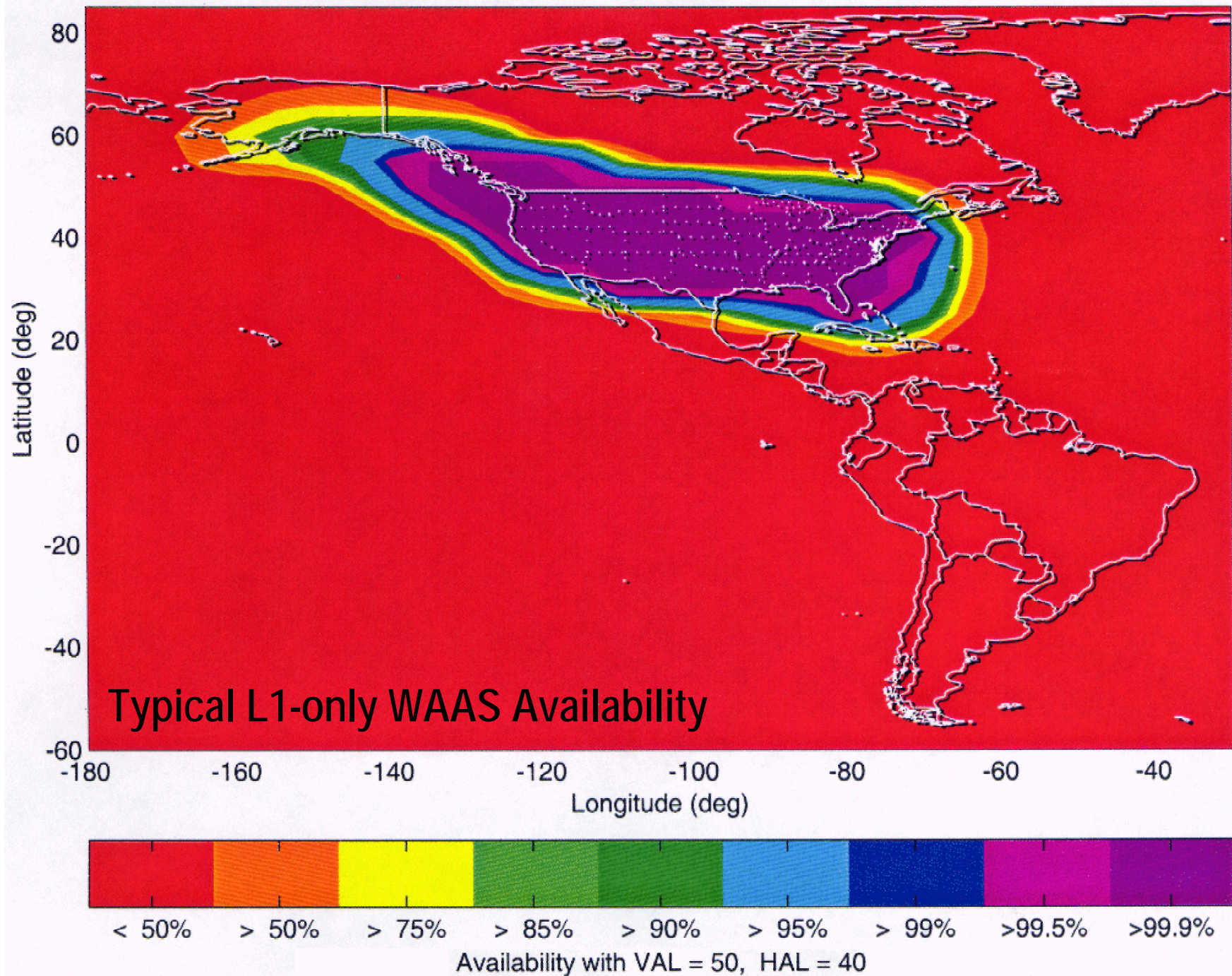
Product Timing Issues

- ◆ Between now and 2017, or later, only L1 will be fully available from both GPS and Galileo
 - This is one reason L1 will remain the primary single frequency signal
- ◆ For many years, L2 will be the primary second frequency for most dual-frequency applications
 - Survey, machine control, agricultural, and scientific receivers far outnumber commercial aviation receivers
 - Only after there are many L5 signals will it become the primary second frequency. When will this happen?
 - There likely will be a transition from L1/L2 to L1/L2/L5 and later a simplification to L1/L5 for best value

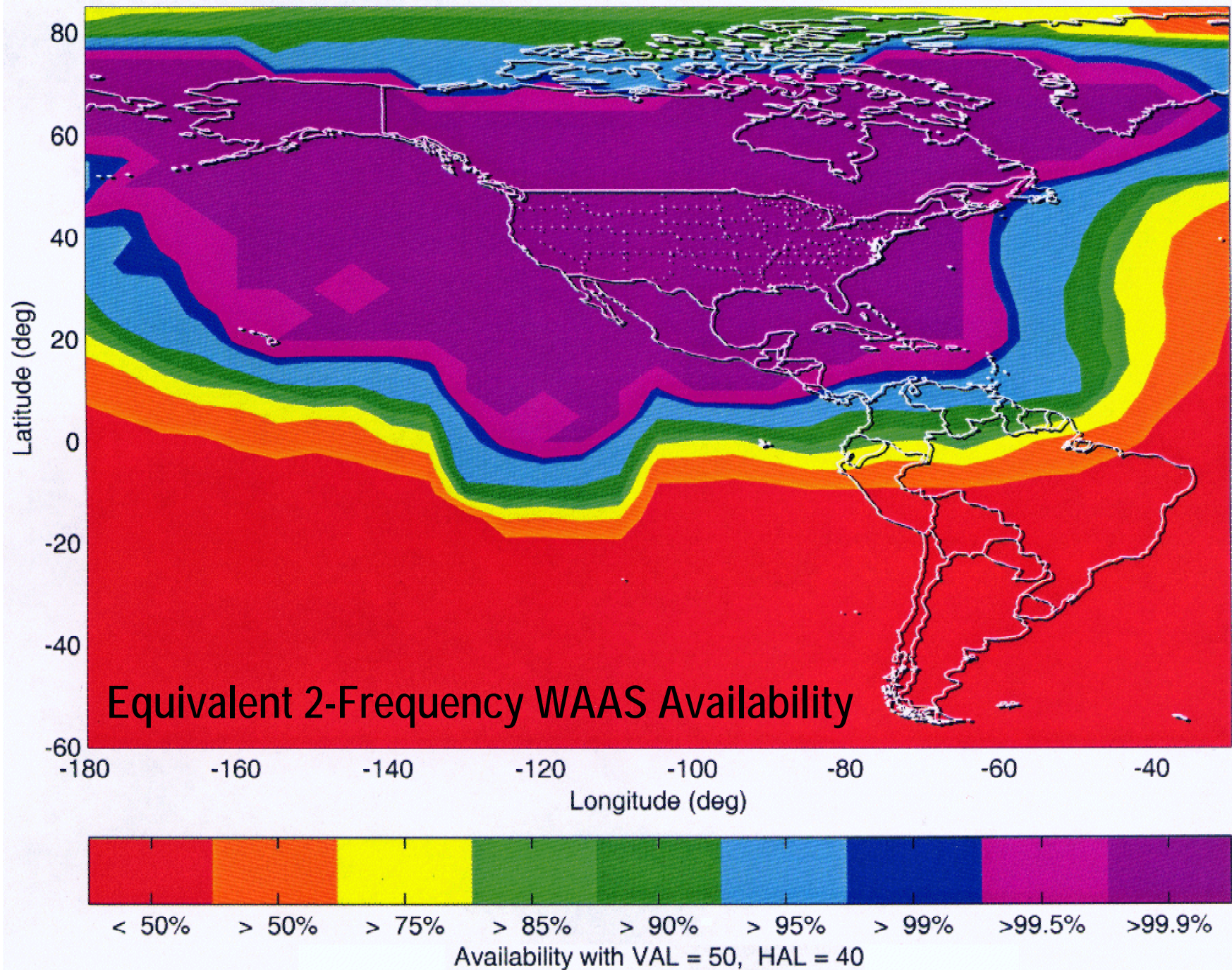
Impact of Dual Frequency on SBAS

- ◆ It requires many SBAS monitor stations to provide adequate WAAS coverage for the continental U.S.
 - This is mainly because it is so difficult to characterize single frequency ionospheric error over a large area
 - At lower (magnetic) latitudes, the ionospheric error is increasingly difficult to characterize, severely restricting SBAS availability
 - Solar activity is expected to peak about 2011, before L5 and E5a are fully deployed, impacting SBAS availability
- ◆ But if dual frequency were widely available

Availability as a function of user location



Availability as a function of user location



Summary

- ◆ It seems to take a very long time, but people are working hard to provide new satellite signals
- ◆ The transition will be difficult for receiver companies and for their users
 - When will my current receiver be obsolete?
 - When should I invest in a new product generation?
 - How long will it retain its value?
- ◆ Communication from satellite providers to the public about the coming transitions is vital to success
- ◆ Users won't know the source of their signals